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A 20-YEAR'S SURVEY OF LASER SCIENCE AND TECHNOLOGY IN CHINA (II--ETC(U)
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FOREIGN TECHNOLOGY DIVISION

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by

Ji Zhong, Qun Li

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By: Ji Zhong, Qun Li

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A 20-YEAR'S SURVEY OF LASER SCIENCE AND TECHNOLOGY IN CHINA (II)

The correspondent Ji Zhong   The reporter Qun Li

VARIOUS TYPES OF COMPONENTS

The research and development on various types of components such as laser materials, light sources, reflective films, etc., have been vital factors in the process of the development of laser technology in China. Those components have direct impact on the quality of lasers. In the 1960's when a variety of lasers were developed, various types of components paved the way for successful operation of a number of laser devices. However, the quality of those components has been more important following a more practical and widespread application of laser technology. Accordingly, the key work to enhance laser applications will be to push research ahead on various types of components and upgrade their quality.

The laser material is the major component. China started to fabricate ruby laser material in 1961. The quality of the material was very close to the best in the world in mid-1960's. At that time, many conferences and workshops were organized in order to obtain large crystals. But, because of failure to meet the requirements, apparently the quality was not comparable to neodymium glass so that the research was isolated from production and ruby lasers were used only rarely. In the past few years, research on the ruby laser material was reinstated and improvements were achieved. For example, the Jianzeh Institute of Laser Research in the province of Honan produced rubies with the flame melting method which improved the laser efficiency about 1% with a possible improvement of 1.7%. The Institute supplied more than

3000 laser bars to nearly 100 units in China recently. Other examples include the pulling method suggested by the Anhwei Institute of Optical Instruments of the Chinese Academy of Science. The ruby grown by the pulling method is better in optical quality and improves the laser beam.

Let us describe the state-of-the-art research in China first. The research on the neodymium glass work material is one of our big projects. There are more than 10 research institutes and plants in the project sharing the duty of fabrication, chemical analyses and manufacturing. They have grown a ϕ120 x 5000 mm bar which was made only rarely in the world. After more than 10 years of effort, their achievements in the research of neodymium glass material, either in techniques, compositions, or in theory* are very impressive. The laser glasses developed and produced by the Shanghai Institute of Optical Instruments are comparable with other leading similar products in the world. Several types of the laser glasses have been exported. The following table lists major properties of those exported laser glasses.

Comparison of properties of ruby crystals grown by the flame-melting method and pulling method

growth method	divergence angle	dimensions	efficiency	institute, date, and updated
flame-melting method	$\leqslant$ 5 m arc	ϕ10 x150 bar 700 joules	average 0.8% max. 1.7%	Jianzeh Institute 1970, past examination, mass production
pulling method	3 m arc(edge need not be shaved)	less 10% than above	>0.7%	Anhwei Inst., end of 1974, under develpmt.

*"On the nonlinear index of refraction of glass and calculation method", <<laser>>, 1979, 6, no. 4, 12. "Study on the spectrum of neodymium phosphide glass and its characteristic of luminescence", <<laser>>, 1979, 6, no. 9, 23.

PROPERTIES OF SEVERAL TYPES OF COMMERCIAL NEODYMIUM GLASS PRODUCED IN CHINA

	TYPE No.		
	N_{1130}	N_{2112}	N_{0312}
Nd_2O_3 (W+%)	3.0	1.2	1.2
stimulated emission cross section (10^{-20} cm^2)	2.5	3.5	1.2
lifetime of fluorescence (μS)	300	350	590
wavelength of fluorescence center (μ)	1.06	1.054	1.06
half bandwidth of fluorescence (μ)	270	265	290
1.06 Å loss coefficient (10^{-3} cm^{-1})	1.0		1.5
laser efficiency (R=50) %	2.0 (φ6x150 mm)		4.0 (φ16x500 nm)
nD	1.560	1.581	1.522
ν	58.0	64.4	59.8
temperature coefficient of refraction index (6328 Å) (10^{-7}/°C)	24	-53	16.4
thermal expansion coefficient (10^{-7}/°C)	105 (20∿400°C)	117 (20∿400°C)	115
thermal-optical coefficient (10^{-7}/°C)	71	7.1	58
stressed thermal-optical coefficient (10^{-7}/°C)		7	
double refracted thermal-optical coefficient (10^{-7}/°C)		4	
transition temperature (°C)	465	497	
deformation temperature(°C)	500	530	
density (g/cm^3)	2.61	3.20	2.51
modulus of elasticity (kg/mm^2)	8860	5360	
modulus of shear (kg/mm^2)	3600		
Poisson's ratio	0.231		

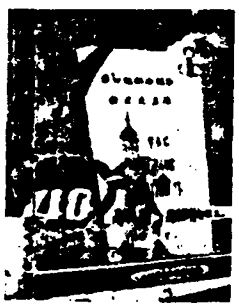
TYPE #	PHYSICAL PROPERTIES: density g/mm³	PHYSICAL PROPERTIES: microscopic hardness kg/mm²	PHYSICAL PROPERTIES: mechanical strength kg/mm²	PHYSICAL PROPERTIES: modulus of elasticity 10³kg/cm²	PHYSICAL PROPERTIES: expansion coefficient 10^{-7}°C^{-1} 15°C~200°C	PHYSICAL PROPERTIES: expansion coefficient 10^{-7}°C^{-1} 15°C~T_s	TECHNOLOGICAL PROPERTIES: transition temp. T_g(°C)	TECHNOLOGICAL PROPERTIES: softness temp. T_f(°C)	TECHNOLOGICAL PROPERTIES: temperature at stiffness of 100 p (°C)
[illegible]112	2.30	560	9.7	679	90	104	500	590	1400
[illegible]112	2.37	560	9.0	720	83	91	560	630	1360
[illegible]312	2.51	605	11.8	759	80	68	590	660	1430
[illegible]12	2.49	615	9.4	727	52	57	590	670	1330
[illegible]612	2.52	623	10.[illegible]	810	87	98	555	610	1270
[illegible]	2.52	557	9.1	647	89	96	495	560	1470
[illegible]12	2.50	551	9.1	647	107	120	545	600	1440
[illegible]912	2.50	533	10.2	687	37	93	620	680	1450
[illegible]124	2.52	585	8.9	750	89	100	525	585	1420

PHYSICAL AND TECHNOLOGICAL PROPERTIES OF SEVERAL TYPES OF GLASS

PROPERTIES OF FLUORESCENCE AND LASER FOR SEVERAL TYPES OF NEODYMIUM GLASSES IN CHINA

type #	lifetime of fluores-cense (μsec)	1.06μm fluorescence half band-width (nm)	φ16x500mm bar laser efficiency	1.06μm absorption coefficient (%/cm)	year	footnote
N_{0112}	600	27	2.4	0.2	1962	fixed type
N_{0212}	620	28	3.0	0.1		unfixed type
N_{0312}	590	29	4.0	0.1	1967	fixed type
N_{0412}	680	28	3.8	0.16	1968	unfixed type
N_{0612}	630	27	2.2	0.29		unfixed type
N_{0712}	690	24	3.5	0.12	1970	fixed type
N_{0812}	760	28	2.7	0.27		fixed type
N_{0912}	750	24	3.8	0.1		fixed type
N_{1024}	510	28	3.5	0.22	1971	fixed type

Laser materials in the early stages included neodymium doped with $CaWO_4$, uranium doped with CaF_2 and tellurium doped with CaF_2 crystals*. Laser outputs were achieved for these laser materials**. However, the most popular crystal to date is still the yttrium-aluminum garnet which was developed in 1965. According to the statistical information, there have been more than 40 units in China participating in the research projects on YAG crystals. After some adjustments in recent years, there are currently around 20 units in the project to pursue high quality materials and produce small amounts of materials. The longest crystal has the dimensions of ϕ40x200mm, with maximum energy conversion efficiency of around 2%. The following picture is the large-scale YAG laser crystal bar.



Among them, the ϕ20x120$\sim$150mm crystal grown at the Northern China Research Institute of Electro-optic Technology using medium frequency inductance heating, low pulling speed and low rotation speed, has a more stable quality. The maximum continuous laser output is as high as 150 watts. The Shanghai Institute of Optical Instruments and the Northern China Institute of Electro-Optical Technology have studied the double-doped (Nd, Cr) YAG crystal. They obtained

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* "CaF_2 high quality single crystal grown by crystal local melting method",<<Science Communication>>, 1964, no. 2, 150.

** "Infra-red excited emission of the $CaF_2:Dy^{2+}$ fluorescent crystal", <<Science Communication>>, 1964, no. 1, 56.
"Infra-red excited emission of the $CaF_2:U^{3+}$ fluorescent crystal", <<Science Communications>>, 1964 no. 1, 57.
"Neodymium doped $CAWO_4$ laser device",<<Science Communication>> 1965, no. 9, 827.

***"Testing report on the neodymium doped yttrium-aluminum garnet (Nd:YAG) crystal", <<Laser and Infra-red>>, 1978, no. 10, 1.

a continuous laser output of 165 watts, along with an efficiency of 2.7%. The Anhwei Institute of Optical Instruments et al also performed research on the double doped (Nd, Lu) YAG. Besides, there are a number of research units performing basic theoretical investigations.

In 1978, a testing conference was held in Beijing. The quality testing results for various YAG crystals are listed in the following table*** (previous page).

There are many other institutes in China developing new laser crystalline materials, such as neodymium-doped $YoAlO_3$, $NdPO_5$, $NdLiPO_4$, LiF_2, $GdMoO_3$, etc. All have been used successfully in lasers*. The following table lists a few new crystalline materials developed by the Northern China Institute of Electro-Optical Technology.

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*"Xenon-lamp pumping NdP_5O_{14} crystal micro pulsed laser device has been working", <<laser>>, 1979, 6, No. 6, 62; "$NdPO_5$ laser device", <<laser>> , 1979, 6, no. 12, 16.

TEST RESULTS FOR VARIOUS YAG CRYSTAL BARS (MAY 1978)
(23 samples from 16 institutes; test results for 16 samples are listed below)

series no.	institute	dimensions and fabrication	growth method	testing unit (1)	decay ratio db/5 cm	internal consumption %/cm^{-1}	large-angle scattering %/cm^{-1} (2)	STATIC PULSE OPERATION: width (joules) (3)	STATIC PULSE OPERATION: differential efficiency (%)	STATIC PULSE OPERATION: total output (joules)	STATIC PULSE OPERATION: total efficiency (%)	CONTINUOUS OPERATION: width (watts)	CONTINUOUS OPERATION: differential efficiency (%)	CONTINUOUS OPERATION: total output (watts)
1	Laolin Univ.	ϕ5.4x73 //2'_2' uniformity 1/2,1/3, illumination, weak	electrical resistance	I	[illegible]	2.4	0.26	2.7	1.12	0.75	1.04	[illegible]	[illegible]	23.4
				II	[illegible]	3.3	14.0	3.2	1.55	0.93	[illegible]	[illegible]	[illegible]	25
				III	[illegible]	7.9	0.86	7.6	1.14	1.03	[illegible]	504	[illegible]	[illegible]
				IV	[illegible]	2.7		4.5	1.32	0.78	[illegible]	1570	[illegible]	[illegible]
				1) 暂定	[illegible]~30		0.26~0.86		1.32				1.73	
2	Ansan Metallic Material Plant	ϕ5.5x65 //10"_30" uniformity 1/2 illumination V	electrical resistance Nd 2% 1.2mm/hr 68 cycles /min	I	10~17	4.8	0.95	4	1.15	0.62	0.57			[illegible]
				II	5~16	8.5	123	2.5	1.56	0.59	[illegible]	[illegible]		[illegible]
				III	10~17	5.4		4.4	[illegible]	0.53	[illegible]	[illegible]		4.5
				IV	6~10	3.4	2.26	2.5	1.22	0.74	1.00			2
				1) 暂定	8~16		0.95~2.26		1.23					
3	Beijing Inst. of Physics	ϕ5.4x79 //15"_30" uniformity 1/5 illumination V	high-frequency Nd 5% 1.3mm/hr 45 cycle/min	I	25~29	1.0	0.25	1.0	0.9	0.70	[illegible]	[illegible]	[illegible]	[illegible]
				II	23~29	2.5	24.0	1.3	1.50	0.95	[illegible]	[illegible]	[illegible]	44
				III	21~27	1.0		1.3	1.68	1.41	1.41	[illegible]	[illegible]	[illegible]
				IV	18~22	2.5	1.12	1.7	1.56	1.54	[illegible]	[illegible]	[illegible]	[illegible]
				1) 暂定	23~29		0.25~1.12		1.56				[illegible]	

Key. 1) tentative

TEST RESULTS FOR VARIOUS YAG CRYSTAL BARS (MAY 1978)
(23 samples from 16 institutes; test results for 16 samples are listed below)

								STATIC PULSE OPERATION				CONTINUOUS OPERATION		
series no.	institute	dimensions and fabrication	growth method	testing unit (1)	decay ratio db/5 cm	internal consumption %/cm^{-1}	large angle scattering %/cm^{-1} (2)	width (joules) (3)	differential efficiency (%)	total output (joules)	total efficiency (%)	width (watts)	differential efficiency (%)	total output (watts)
5	Beijing Chemical Plant	ϕ5.5x76/[illegible] 1'30" uniformity 1/4 illumination not good	electrical resistance	I	[illegible]	[illegible]	0.33	2.5	1.47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				II	[illegible]	3.3	45	[illegible]	1.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				III	[illegible]	2.3		3.4	[illegible]	1.05	[illegible]	[illegible]	[illegible]	[illegible]
				IV	7~[illegible]	3.5	1.23	3.5	1.42	[illegible]	1.18	[illegible]	[illegible]	[illegible]
				[illegible]	10~21		0.33~1.23		1.42				[illegible]	
7	Northern Chinese Institute of Electro-optical Technology	ϕ5.5x75 /30' 1' uniformity 1/3, 1/4 illumination III,V	medium frequency double doped, 1.24mm/Hr	I	37	1.4	0.21	1.3	1.56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				II	[illegible]	1.6	30.5	1.0	1.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				III	[illegible]~33	3.[illegible]		2.7	1.85	0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				IV	[illegible]	1.5	5.30	1.8	1.32	1.03	1.20	[illegible]	[illegible]	[illegible]
				[illegible]	24~[illegible]		0.21~5.30		1.32				[illegible]	
8	Shanghai Institute of Optical Instruments	ϕ5.5x73	electrical resistance Nd 3% 2 mm/hr 90-50 cycles/min	I	27~[illegible]	1.1	0.3	1.6	1.14	0.77	1.07	[illegible]	[illegible]	[illegible]
				II	24~[illegible]	2.4	33	1.3	1.4	0.91	1.24	[illegible]	[illegible]	[illegible]
				III	[illegible]	2.4		3.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				IV	[illegible]	2.9	0.66	2.0	1.3	0.95	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	24~32		0.3~0.66		1.3				[illegible]	

Key: 1) tentative

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(23 samples from 16 institutes; test results for 16 samples are listed below)

series no.	institute	dimensions and fabrication	growth method	testing unit (1)	decay ratio db/5 cm	internal consumption %/cm^{-1}	large angle scattering %/cm^{-1} (2)	STATIC PULSE OPERATION: width (joules) (3)	STATIC PULSE OPERATION: differential efficiency (%)	STATIC PULSE OPERATION: total output (joules)	STATIC PULSE OPERATION: total efficiency (%)	CONTINUOUS OPERATION: width (watts)	CONTINUOUS OPERATION: differential efficiency (%)	CONTINUOUS OPERATION: total output (watts)
11	Shanghai Oriental Meter Plant	ϕ5.5x71 //40"_30" uniformity 1/2 illumination, weak	electrical resistance	I	[illegible]~30	1.8	0.19	2.5	1.54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				II	[illegible]~28	1.7	13	1.4	1.03	1.18	1.65	[illegible]	[illegible]	[illegible]
				III	[illegible]~31	1.6		3.6	1.10	[illegible]	1.00	[illegible]	[illegible]	[illegible]
				IV	[illegible]	1.8	0.9	1.7	[illegible]	[illegible]	1.00	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]		0.19~0.90		2.00				[illegible]	
14	Yangzhou 5308 Plant	ϕ5.6x71 //10"_1' uniformity 1/4 illumination	electrical resistance	I	31	1.1	0.8	1.3	1.52	0.96	1.37	[illegible]	[illegible]	[illegible]
				II	29~32	1.9	26	1.2	2.0	1.33	1.87	[illegible]	1.72	[illegible]
				III	[illegible]	[illegible]		4.0	1.3	[illegible]	[illegible]	[illegible]	[illegible]	25
				IV	24~27	2.3	1.1	1.7	1.4	1.04	[illegible]	[illegible]	[illegible]	31
				暂定	29~32		0.8~1.1		1.4				[illegible]	
15	Eastern Chinese School of Engineering	ϕ5.9x70 //10"_1' uniformity 1 illumination III,V	electrical resistance	I	[illegible]~18	1.4	0.26	1.2	1.54	1.0	1.45	[illegible]	1.2	[illegible]
				II	12~14	1.5	15.0	0.7	1.71	1.2	[illegible]	[illegible]	[illegible]	[illegible]
				III	[illegible]~18	1.3		2.2	1.40	1.2	[illegible]	[illegible]	[illegible]	[illegible]
				IV	[illegible]~9	1.8	0.98	1.3	1.88	1.29	1.65	[illegible]	[illegible]	[illegible]
				暂定	12~14		0.26~0.98		1.88				[illegible]	

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series no.	institute	dimensions and fabrication	growth method	testing unit (1)	decay ratio db/5 cm	internal consumption %/cm⁻¹	large angle scattering %/cm⁻¹ (2)	STATIC PULSE OPERATION: width (joules) (3)	STATIC PULSE OPERATION: differential efficiency (%)	STATIC PULSE OPERATION: total output (joules)	STATIC PULSE OPERATION: total efficiency (%)	CONTINUOUS OPERATION: width (watts)	CONTINUOUS OPERATION: differential efficiency (%)	CONTINUOUS OPERATION: total output (watts)
17	Nanjing Glass Plant	:5.6x70 //5"_15" uniformity 1-1/2 illumination, III	high-frequency Nd 3% 1.3 mm/hr 60 cycles/min	I	13~15	2.3	0.27	1.4	[illegible]	0.92	[illegible]	[illegible]	[illegible]	[illegible]
				II	11~15	1.2	32	0.8	1.78	1.20	[illegible]	[illegible]	[illegible]	39
				III	11~15	3.0		2.5	[illegible]	0.63	[illegible]	[illegible]	[illegible]	[illegible]
				IV	7~[illegible]	2.0	1.07	1.5	1.53	[illegible]	1.45	[illegible]	[illegible]	[illegible]
				暂定	11~15		0.27~1.07		1.53				[illegible]	
18	Jinan Semi-conductor Plant	/5.5x69 //30"_30" uniformity 1/5 illumination, bad	electrical resistance	I	25~29	1.8	0.42	1.5	[illegible]	1.21	1.78	[illegible]	1.2	[illegible]
				II	22~30	1.8	34	1.0	[illegible]	1.0	[illegible]	[illegible]	1.1	[illegible]
				III	23~29	3.7		2.3	1.4	1.1	1.1	[illegible]	1.0	[illegible]
				IV	0~28	2.5	1.05	1.6	1.7	1.28	1.6	[illegible]	1.3	[illegible]
				暂定	22~30		0.42~1.05		1.7				1.3	
19	5th Machine [illegible] Division 2[illegible]	:5.4x71 //5"_1' uniformity 1/4 illumination, III	electrical resistance Nd 3.5%	I	4~6	1.0	0.26	1.0	2.21			945	[illegible]	[illegible]
				II	4~8	1.7	11	0.7	2.50	1.74	2.45	[illegible]	[illegible]	[illegible]
				III	5~7	4.8		3.5	1.70	1.25	1.26	[illegible]	[illegible]	[illegible]
				IV	3~4	2.3	0.86	1.1	1.73	1.26	1.50	[illegible]	[illegible]	43
				暂定	4~8		0.26~0.86		1.73				[illegible]	

Key: 1) tentative

TEST RESULTS FOR VARIOUS YAG CRYSTAL BARS (MAY 1978)
(23 samples from 16 institutes; test results for 16 samples are listed below)

series no.	institute	dimensions and fabrication	growth method	testing unit (1)	decay ratio db/5 cm	internal consumption %/cm^{-1}	large angle scattering %/cm^{-1} (2)	STATIC PULSE OPERATION: width (joules) (3)	differential efficiency (%)	total output (joules)	total efficiency (%)	CONTINUOUS OPERATION: width (watts)	differential efficiency (%)	total output (watts)
20	Chundu Plant 238	5.6x78 //30"_30" uniformity 1/3 illumination, II,III	electrical resistance 1.5mm/hr 95.98 cycles/min	I	[illegible]~27	1.2	0.37	1.0	1.57	1.08	1.5	[illegible]	1.5	[illegible]
				II	20~26	1.4	16	0.7	1.34	0.97	1.32	970	1.9	[illegible]
				III	20~23	2.8		2.3	1.30	1.14	1.14	540	4.0	[illegible]
				IV	15~[illegible]	1.5	0.09	1.3	1.48	0.94	1.10	[illegible]	[illegible]	[illegible]
				暂定	20~[illegible]		0.27~0.99		1.48				1.8	
21	Chundu Semi-Conductor Plant	5.5x70.5 //10"_15" uniformity 1/8 illumination V,VI	electrical resistance Nd 3% 1.33 mm/hr 83 cycles/min	I	20~[illegible]	1.0	0.24	1.2	1.37	0.92	1.31	[illegible]	[illegible]	[illegible]
				II	22~25	1.5	16	0.8	1.6	1.03	1.45	[illegible]	1.54	35
				III	21~26	1.3		2.8	1.15	1.11	1.11	400	3.40	[illegible]
				IV	6~22	1.5	0.75	1.5	1.4	0.95	1.20	1300	1.73	35
				暂定	22~25		0.24~0.75		1.4				1.73	
22	3rd Machine Quarter, Division 013	5.7x76 //30"_1" uniformity 1/3 illumination, bad	doping Nd 4% Lu 7.2%	I	27~30	1.3	0.41	1.5	1.12	0.92	1.02	[illegible]	1.03	[illegible]
				II	15~25	2.5	19	1.1	1.3	0.97	[illegible]	[illegible]		28
				III	18~28	3.3		2.8	1.17	0.90	0.93	[illegible]	0.92	[illegible]
				IV	11~22	3.0	0.95	1.8	1.76	1.28	1.60	[illegible]	1.9	[illegible]
				暂定	15~28		0.41~0.95		1.76				[illegible]	

Key: 1) tentative

TEST RESULTS FOR VARIOUS YAG CRYSTAL BARS (MAY 1978)
(23 samples from 16 institutes; test results for 16 samples are listed below)

series no.	institute	dimensions and fabrication	growth method	testing unit (1)	decay ratio db/5 cm	internal consumption %/cm	large angle scattering %/cm^{-1} (2)	STATIC PULSE OPERATION: width (joules) (3)	differential efficiency (%)	total output (joules)	total efficiency (%)	CONTINUOUS OPERATION: width (watts)	differential efficiency (%)	total output (watts)
	5th Machine	6.5x72	electrical	I	19~22	3	1.44	3.1	1.04	0.65	0.94			
	Quarter	7/15"12'	resistance	II	17~20	1	138	2.2	1.50	[illegible]	1.33			
23	Division	uniformity	1.5 mm/hr	III	19~22	5		5.2	0.8	0.66	0.66			:
	205	1/2,1/4	84 cycles/	IV	[illegible]~15	4	2.0	3.9	1.2	0.78	0.9			
		illumination III	min	T.S.	17~20		1.44~2.0		1.2					

Key: 1, tentative
Notes:
(1) Measurement Institute: I. Shanghai Institute of Optical Instruments; II. Shanghai Oriental Meter Plant; III. Shanduong University; IV. Northern Chinese Institute of Electro-optical Technology. Tentative values: Decay ratio from Oriental Meter Plant data, large angle scattering from Shanghai Institute of Optical Instruments and Northern Chinese Institute of Electro-optical Technology, static efficiency and continuous differential efficiency from Northern Chinese Institute of Electro-optical Technology.
(2) Large angle scattering: The Shanghai Institute of Optical Instruments employed 1.06 μm light source, the Northern Chinese Institute of Electro-optical Technology employed 6328 Å light source.
(3) Static pulse testing performed by the Shanduong University with additional pipe gave much lower data.
(4) Measurement condition: Input power: Shanghai Institute of Optical Instruments, Oriental Meter Plant, 3kW, Shanduong University, 2.5 kW; Northern Chinese Institute of Electro-optical Technology, 4.3 kW.

NAME OF CRYSTAL	YEAR OF DEVELOPMENT
Nd, F-doped $CaPO_4$	1971
Nd-doped CaYo SiO_3	1973
Er-doped $LiYoF_2$	1977
Ho-doped $GdMoO_3$	1978
Ho-doped $LiYoF_2$	1978
Nd-doped $LaAlO_3$	1978
Tb-doped $CaYoO_2$	1978
Nd-doped $YoFmO_3$	1979
Tb, Dy-doped $GdMoO_3$	1979
Nd-doped $GdMoO_3$	1979
$GdMoO_3$	1979
Er-doped $GdMoO_3$	
Ho-doped $GdMoO_3$	

The research on laser light sources corresponds to the development of laser devices. The light sources include the high-energy pulsed xenon lamp, high-power pulsed zenon lamp, repetitive frequency xenon lamp and continuous krypton lamp, etc. When categorized by shape and structure, there are the spiral type, straight-pipe type as well as coaxial type. The most popular one is the straight-pipe light-pumping source. For the past few years, there has been impressive progress made on the techniques in light source production so that the lifetime of light sources and power level have been greatly upgraded.

1. Frictional coating, indium sealing technique--realizes the sealing of quartz, glass and copper, silver, etc., with gas leakage rate $<10^{-11}$ Torr, liter/sec.

2. Quartz and tungsten high-temperature sealing technique--employs sealing glass as the transition layer between the quartz and tungsten bar; can be operated at 700∿800°C temperature for a long time; the diameter of the largest tungsten sealed is 4 mm;

quality of the sealing exceeds 10^{-10} Torr, liter/sec.

3. Copper cap and lead-filled quartz technique--can seal a quartz pipe of $\phi 150 \sim 200$ mm in diameter.

Developments and qualities of various light-pumping laser sources in China are listed in the following table:

HIGH-ENERGY PULSED XENON LAMPS

TYPE	DIMENSIONS: lamp lgth mm	dist. btwn electrode mm	outer dia. mm	inner dia. mm	SQUARE WAVE DISCHARGE PARAMETER: capacity μF	dis-chg time ns	max load joules	resistivity 52.cm
TEP-50×310	520	310	50	45	21600	20	35×10^4	~0.03
TEP-50×500	710	500	50	45	21600	20	57×10^4	~0.03
TEP-50×1000	1210	1000	50	45	21600	20	115×10^4	~0.03
TEP-50×1800	2010	1800	50	45	21600	10	156×10^4	~0.023
	2010	1800	50	45	21600	20	212×10^4	~0.028
	2010	1800	50	45	21600	40	360×10^4	~0.031
TEP-50×2250	2460	2250	50	45	21600	20	258×10^4	~0.023

HIGH-POWER PULSED XENON LAMPS

TYPE	DIMENSIONS: lamp lgth (mm)	dist btwn electrode (mm)	outer dia. (mm)	inner dia. (mm)	PARAMETERS USED: capacity μF	oper. volt. KV	discharge pulse width msec	radiation efficiency %	lamp resist.	lighting freq. /min	life-time no.	max load 10^4 joules
TMS-15×500												
TMS-20×480	680	480	20	16	900	4.5	0.43	60	0.48	1	>2000	1.5
TMS-25×500	700	500	25	21	2000	4	0.40	60	0.35	1	>2000	2.5
TMS-30×480	680	480	30	26	3000	4	0.50	60	0.23	1	>2000	3.0
TMS-35×600	800	600	35	31	3000	4	0.78	55	0.26	1	>2000	6.5
TMS-35×1100	1300	1100	35	31	1750	7	1.2	55	0.70	1	>1000	8.0
TMS-50×330	550	330	50	45	4000	4	0.8	40	0.05	1	>100	5.5

REPETITIVE-FREQUENCY PULSED XENON LAMPS

TYPE	DIMENSIONS (MM) lamp length	dist. btwn electrode	outer dia.	inner dia.	PARAMETERS USED freq. /sec	max volt. V	single pulse energy joules	explosion energy joules	pulse width μsec	cooling water ℓ/min	lifetime no. of pulses
GPMX-8×50	150	50	8	6	800	20~100	20	300	70	>6	$>10^7$
GPMX-8×70	170	70	8	6	1150	20~100	30	500	70	>6	$>10^7$
GPMX-8×120	210	120	8	6	1350	20~100	50	1200	100	>6	$>10^7$
GPMX-10×80	210	80	10	8	1350	20~100	70	1700	100	>6	$>10^7$
GPMX-10×100	212	100	10	8	2000	20~100	110	2500	150	>6	$>10^7$
GPMX-12×100	222	100	12	9	1350	20~100	90	2000	150	>6	$>10^7$
GPMX-12×120	242	120	12	9	2000	20~100	135	3000	180	>6	$>10^7$
DPMX-8×110	220	110	8	4	10000	20~40	10	400	<2	>6	$>10^6$

CONTINUOUS Kr ARC LAMPS

TYPE	DIMENSIONS (MM) lamp lgth	dist. btwn electrode	outer dia.	inner dia.	OPERATION PARAMETERS oper. current amp.	oper. volt. V	power watts	cool-water flux ℓ/min	cumulative lifetime hrs
LK-8×75	200	75	8	6	35±2	132±3	4500	25	100
LK-10×100	235	100	10	8	44±2	136±3	6000	25	50
LK-10×120	255	120	10	8	48±2	167±3	8000	25	50

STATE OF THE ART THIN FILM DEVELOPMENT IN CHINA

	WAVELENGTH	GENERAL LEVEL	MAX. LEVEL
high reflectivity film	6328 Å soft film hard film	vertical reflectivity % 99.5∿99.8 90.0∿99.5	vertical reflectivity % ∿99.9 99.8∿99.99
	1.06 m soft film hard film	99.5∿99.8 99.0∿99.5	99.8∿99.9 ∿99.8
		the anti-laser strength for hard film: for 1.06 μm power laser $>10^{10}$ W/cm^2; for 1.06 μm YAG continuous output laser (light beam∿φ3),200W	
reduced reflectivity film	visible to near infra-red unique wave-length	residual reflectivity ∿0.1%	<0.05%
	1.06 μm GaAs window Ge window	transparency >98% transparency >90%	anti-laser strength: >1000 W/cm^2 >100 W/cm^2
interference filtering slice	6328 Å 6943 Å	half-width 40∿60 Å transparency 70∿75%	
	1.06 μm	half-width 100 Å transparency 70∿75%	50 Å∿55%
	1.06 μm		700 Å ≥40%
polarized oscillation film	1.06 μm	S component trans-parency = 2% p component trans-parency = 96%	S component trans-parency ∿0.3% p component trans-parency ∿98%

The thin film technology has been continuously developed in China. Moreover, we have a compatible technical team and high-quality apparatus. In terms of current laser devices, four major types of thin films are listed in the above table with technical levels described.

Electro-optical, nonlinear materials are popular crystals used for Q-modulation, frequency-multiplication in laser devices. China started research on them quite early. In 1957-1958, Siamen

QUALITY STATISTICS FOR NONLINEAR MATERIALS

INSTITUTE	name of crystal	Molecular formula	Frequency multiplication efficiency	double reflectivity	transparency wavelength	development date
Fujian Inst of Material Structures	ADP	$NH_4H_2PO_4$	electro-optical modulation	$\sim 10^{-5}$/cm	2100~17000 Å	1965
	KDP	KH_2PO_4	frequency multiplication transition efficiency ~10%	$\sim 10^{-6}$/cm		1965
Sandoun Univ	KD*P	KD_2PO_4	electro-optical	$\sim 10^{-5} \sim 10^{-6}$/cm	2500~2x10^4 Å	1976
Silica Inst [illegible] Plant [illegible] [illegible] Plant 405	lithium niobate	$LiNbO_3$	electro-optical modulation, frequency multiplication	$\sim 10^{-5}$/cm	3500~5x10^4 Å	Silica Inst. started in 1967
Sandoun Univ. [illegible] Plant 999	lithium tantate	$LiTaO_3$	electro-optical modulation	$\sim 10^{-4}$/cm	3500~5x10^4 Å	~1973 ~1974
Silica Inst		$Ba_2NaNb_5O_{15}$	multi-frequency transition efficiency ~30%	$\sim 10^{-4}$/cm	3500~5x10^4 Å	1976
Inst. of Physics Inst. of Material Structure Sandoun Univ.	lithium iodite	$LiIO_3$	~15~20%	$\sim 10^{-5}$/cm	3500~5x10^4 Å	1971~1972

University started to study the $NH_4H_2PO_4$ (ADP) crystal which was then used as a piezoelectric material. Since lasers were invented, the crystal was promptly applied to the electro-optical modulation and frequency multiplication research. Although it is similar to KH_2PO_4, (KDP) the modulation coefficient and transition efficiency are not ideal. Like KH_2PO_4, a large single crystal with excellent optical uniformity can be grown. As a result, the crystal is still widely adopted. Besides, many institutes have grown new crystalline materials, such as $LiNiO_3$, $LiTaO_3$, $LiIO_3$, $Ba_2NaNb_5O_{15}$, etc. The table (page 18) lists characteristics of several nonlinear materials and their manufacturers.

Since the last one or two years new nonlinear crystals also include: LiH_2O_5, K BO_5 $BeSO_4$, light red silver crystal*, etc. The Fujien Institute of Material Structures also investigated some organic nonlinear materials and grew some crude samples. One of the samples is SN** for which some tests indicated that the SN is superior to ADP in the nonlinear effect, but is inferior to $LiIO_3$ in that regard.

Since the wavelength range for lasers has been continuously expanded, the requirement for laser device window materials has been upgraded consequently. As a result, new varieties of window materials have been increased constantly. Currently, those materials include optical glass, NaCl, KCl, Ge, GaAs, etc. Besides, CaF_2 crystal is an excellent infra-red material which is characterized by broad spectral transparency range, high transparency, uniform dispersion, etc. The Chunchun Institute of Optical

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* "Nonlinear Materials--The growth of a light red silver crystal", "Laser", 1979, 6, no. 7, 51.

**"The growth of a SN crystal and its multi-frequency effect", "National Conference on the Crystal Growth and Material Science--Digest", 1979, B11, 32.

Instruments recently grew a piece of CaF_2 single crystal: ϕ190 mm, weight 15 Kg. This is comparable with leading products in the world. The Guanjou Institute of Electronic Technology of the Chinese Academy of Science has produced TlBrI with a transparency of 60∿70% (1-30 μm range). Many institutes also developed larger ruby crystals with better optical properties.

UP AND DOWN

Laser technology found its applications in less than a year after the invention. This rarely happened before. However, for any new technology, the development of its applications is normally affected by our perception of the technology and by the development of the technology itself. Applications of laser technology in China face problems regarding the perception and constant improvement of the technology itself. As a result, there has been a fever in China on the applications of laser technology, but the fever was hampered soon after certain requirements could not be met. With continuous improvement on laser technology and solution of some key problems, many new applications were developed again. In other words, the fever was up and down in various application fields. This reflects an episode of the development of laser technology in China.

Applications of laser technology were in the preparation and initial stage in 1960. In particular, the technology was well applied to hole drilling, calibration and distance measurement. In the 1970's, broad applications were opened up and a surge of application development developed in every scientific field. Such powerful penetration and influence led to a new tool for every field and also provided a useful tool for economic construction.

I. Industrial applications of lasers

Research on the industrial applications of lasers was

initiated soon after the first ruby laser device was successfully operated in China. In 1963, the first ruby laser hole-drilling machine appeared in an exhibition held in Beijing and drew a lot of attention. The Shanghai Clock and Watch Component Plant was the first to apply laser technology to the manufacture of axis pivots. Testing was started in 1965 and finally mass production was realized. The picture shown below is the product line using laser hole-drilling machines. Besides its application in the clock and watch industry, laser drilling technology was also applied for nozzles of diesel engines. The outcome is also very impressive. The application of laser drilling technology has been going on so long in China that the technology has reached a ripe stage. Currently research effort is concentrated on the upgrading of drilling frequency for which a high-repetivity laser output of 14/sec has been obtained. If the quality of the laser output beam could be successively improved, further applications of laser drilling technology are very hopeful.

Production line of axis pivot for watches using a laser drilling machine

It is well known that laser technology can be applied to cutting steel plate, titanium plate, quartz, ceramic, etc., which are materials with a high-melting point. But it is a long way to design a practical machine to fulfill the ideal. The National Committee of Science initiated a testing workshop in Chunchun in September, 1979. An SJ-2500 numerically controlled laser cutting machine was examined at the workshop. The machine was developed cooperatively by the Sedan Plant of the Chunchun First Automobile Manufacture Plant, Chunchun Institute of Optical Instruments, Jilin Provincial Institute of Mechanical Design and the Chungching Institute of Design of the First Machine Division. This laser cutting machine is capable of cutting a thin steel plate of complicated shape which is less than 6 mm thick and is

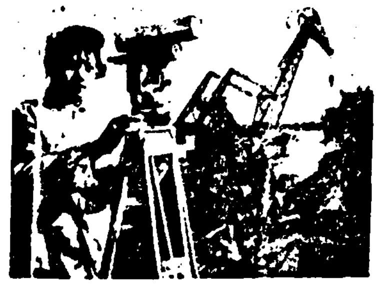
required by the automobile industry*. The characteristics of this machine include very narrow cutting track (about 0.3 mm), uniform cutting edge, small amounts of oxide residues, small thermal influence region, etc. In more than two years of preliminary production, more than 20 materials and more than 20 operations were tested with more than 30,000 kilometers of steel plate length involved. Accordingly, its success certainly will aid the shipbuilding and aviation industries in China. It also demonstrated its superiority over many other products and so filled a gap developed in laser technology in the past years.

Numerically-controlled laser cutting machine

The application of laser calibration technology is very widespread in China. The high-directional characteristic of the laser has been utilized for calibration. The tool, as a result, should not be affected by any environmental condition. Laser calibrators, laser longitude-latitude calibrators, laser directional devices, etc., have been developed for mass production. Other applications of laser calibration are in giant shipbuilding, airborne installations, high-rise buildings, bridge construction, highway construction, underground pipelines, underground railroads, tunnel construction, coal mine drilling, canal drilling, etc. The new technology has demonstrated its capacity in these applications. The following picture shows the application of the laser longitude-latitude calibrator in the shipbuilding industry.

Industrial applications of laser technology also include microwelding, precise measurement, etc. There are more than 40

*"Numerically controlled laser cutting machine", "Laser", 1977, 4. no. 5, 17.



Application of the laser longitude-latitude calibrator in the shipbuilding industry

types of laser devices in mass production in China. Some others are under development. The following table lists major laser device products manufactured in the First Machine Division System:

SEVERAL MAJOR LASER DEVICE PRODUCTS

Name of product	Major technological capabilities	Name of product	Major technological capabilities
JG-11 type automatically compensated laser interferometer	1. stable and reliable operation in the range of 0~20 m; 2. resolution 0.1 μm; 3. accuracy of measurement; Stabilized temperature in a measurement room: ±1 μm/m Production line: ±2 μm/m 4. measurement speed: >10 m/min 5. environmental parameter correction transceiver accuracy of temperature transceiver: ± 0.1°C (8~32°C) accuracy of pressure transceiver ± 1 mm Hg (600~800 mm Hg)	WDJ-1 laser monochromator	1. modulation range: with multiple dyes depending on the need, 3800~7000 Å; 2. accuracy of wavelength ±1 Å, output stability <0.05 Å/°C; 3. number of times dye can be replaced: 6 4. output spectral width: without calibrator < 1 Å (at 6000 Å) with calibrator <0.1 Å (at 6000 Å) 5. single-pulse output transition efficiency >8% (light grating modulation) 6. divergence of light wave θ/2 ⩽ 5 m arc 7. accuracy of wavelength calibration θ< ± 0.5 Å

Name of product	Major technological capabilities
laser silk structure dynamical detector	1. length of measure silk structure 1m, 3m, 5m 2. accuracy: zero order for less than 1m, one order less than 2m
single-module stable frequency laser interferometer	1. measurement range: 0∿20 m 2. minimum resolution: 0.1 μm 3. speed: 2m/min
laser length measurement machine (1,3m)	1. measurement range: 0~1000mm 0~3000mm 2. error: $\pm(0.2\ \mu m + 10^{6} \ell)$
high accuracy silk structure grinder laser automatic calibration device	stable grinding and cutting, zero-order accuracy
liquid surface supersonic damage detector	currently a φ 1 mm artificial defect indicator in a 16mm thick aluminum plate can be detected by the experimental apparatus
double directional laser diameter measurer	measurement range φ5∿ φ30 mm measurement error <±0.05 mm
laser micro-region spectrum analyzer	1. relative sensitivity 0.01∿0.001% 2. absolute sensitivity: 10^{-9}∿10^{-12} gm 3. sample diameter: 10∿100 μm, can analyze more than 60 elements

Name of product	Major technological capabilities
	8. speed of wavelength scanning (when using light grating scanning 30 Å/min, 750 Å/min
laser Raman spectrophotometer	1. operational spectral range: 4000∿ 8500 Å 2. wave number repetivity: entire wave block is ±1 cm^{-1}
J_2-JD laser longitude-latitude calibrator	1. accuracy of angle measurement: error in horizontal direction ±2 sec 2. divergence of light beam: diameter of light spot at 100 m is about 5 mm
laser calibrator	maximum calibration distance: 100 m, repetivity accuracy: 0.05mm
JZY-1 type laser direction device	distance: 1000 m diameter of light spot < 60 μm
JD-2 type laser direction device	explosion-prevention type distance for one operation 5000m
phase type long range distance measuring device	daytime measured distance over 40 km accuracy $\pm(5mm+0.8\times10^{-6}D)$ operation temperature 0∿40°C

Name of product	Major technological capabilities	Name of product	Major technological capabilities
CLS-95 type plane interferometer	measure small angle for optical components; plane accuracy $\lambda/15$; parallel accuracy 1 sec	short-range infrared electric distance measurer	measurement range: 0∿2 km; accuracy: ±1.5 cm; operation temperature: -15∿40°C
J_{74}-1 type laser expansion device	measure thermal expansion properties for metallic and non-metallic materials; measurement accuracy $\pm 0.1 \pm 10^{-6}/°C$		

II. Agricultural applications of lasers

Research on agricultural applications of lasers in China was started late, about 1972. There are currently over 100 units in about 20 provinces and cities involved in the business. Among them, Guandoun Province, Hunan Province and Suchuan Province are most active. In Guandoun Province, there have been more than 80 communities (including production groups, there will be over 130 units), which have performed testing. Two nationwide symposia on agricultural applications of lasers have been held before. One was held in Fuoshan of Guandoun in December, 1974. There were 81 departments and units from 18 provinces and cities which sent representatives to the symposium. The symposium was initiated by the Chinese Academy of Science. The second symposium was held in Beijing in December, 1975 which was attended by 115 representatives from more than 80 units in 25 provinces and cities.

Lasers have been employed to test the growth of crops, vegetables, fruit trees, silk worms, etc., of more than 20 varieties. Laser illumination testing has also been applied to animals such as pigs, ducklings, fish, microbes, etc. The test results have been proven very fruitful, particularly in rice, oil vegetable,

silk worms, etc. For example, laser fostered "Keji" #1, #2, #27, #28, #29, etc., have been widely planted and an increase of 60~100 catty per mu yield has been achieved, the oil vegetable seeds fostered by laser also enhanced production. In the Chingpu County of the city of Shanghai, one tenth of the available oil vegetable farm area (9000 acres) is planted with laser fostered oil vegetables, showing an average increase of 10~25% in product.

Home silk worms and Bima silk worms treated by lasers have been grown to the fifth generation and 31st generation respectively. The new species of home silk worms is larger and has more silk output (about 18%) compared to the regular ones. A new species of Bima silk worms shows varieties of transmutations which are retained for many generations. It is also larger than a regular one.

The worm-killing effect of laser fostered fungi has been upgraded to over 60% in comparison to 30% with regular fungi.

In summary, after several years of primary testing, some results have been observed. For example, laser irradiated crop seeds can speed up the growth of sprouts along with a healthy set time, there is early ripening, upgrading of worm-resistant potential, etc. But many results need further examination and proof. It is hoped that well organized, well planned scientific experiments will open up a new technological path for agricultural development in China.

III. Research on medical applications of lasers

Research on medical applications of lasers was started early in China. In 1965, a ruby treatment machine was successfully operated and was tested on rabbits, mice, dogs, monkeys, etc. Later, a CO_2 laser treatment machine was used to cut animal skin and internal organs. In 1970, laser clinical treatment was widely

applied to various diseases in China. Currently, there are about 200 institutes performing laser treatment clinical testing (more than 50 factories manufacturing treatment machines and more than 40 institutes in charge of research and development), while there are more units performing laser treatment. More than 130 types of diseases have been treated, including eye diseases, skin diseases, cancers, etc. Clinical experiences have been substantially accumulated. In particular, laser surgery of the iris is comparable to the leading technique in the world. Laser treatment of cancer is more emphasized in China; in particular, the treatment of skin cancer has demonstrated its effect. A hospital in Shanghai has cured 73 types of skin cancer with the laser vaporization method. The efficiency is about 96%. 40 types of skin cancer were given up on using conventional treatment methods (i.e., surgery, anti-cancer medicines, radiation treatment were all ineffective). With laser vaporization treatment, 76.7% of patients can survive more than 2 years, 22 patients recover their normal life and work regularly. 96.2% of 26 patients who might survive under conventional treatment now survive for more than 2 years.

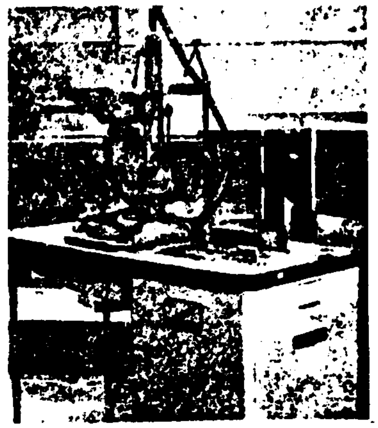
Besides, the clinical performances in the past few years indicate that the He-Ne laser is remarkable in the treatment of rectum diseases, etc. In the meantime, the CO_2 laser is used to treat blood vessel cancer, etc., with an efficiency of 90%.

In order to upgrade research on medical applications of lasers, a national laser medicine and laser treatment machine technology conference was held in Wuhan in June, 1977. 410 representatives from 243 units located in 23 different provinces and cities attended the conference. Besides, many provinces and cities have sponsored their own conferences regarding laser medicine.

The research for medical applications of lasers was started with eye diseases. Currently, there are more than 20 institutes

located in 16 different provinces and cities, in the process of developing laser treatment machines for eye diseases. More than 20 types of eye diseases have been treated. In particular, good results have been demonstrated for retinal condensation, iris surgery, closed retinal splitting, blood vessel development on central retina, blood vessel cancer, etc.

JG-75-1 type laser iris surgery machine



CO_2 lasers and YAG lasers have been used in burning and cutting cancer growing in the mouth or on the face. Blood vessel cancer developed in the mouth was treated by radiation or with freezing methods in the past, but the outcome was not satisfactory. If conventional surgery was used, some oral functions might be handicapped or some unusual shapes might develop. On the contrary, laser treatment not only leads to a satisfactory clinical effect and, in the meantime, maintains every function in normal condition, but also keeps the mouth and face in their original shapes.

Acupuncture is a traditional, widespread treatment in China. It has been employed for thousands of years. Light beams stimulate some key locations in the body of a human being. This characteristic has been applied to modern medical treatment. Since the invention of lasers, medical workers, of course, pursued applications of lasers to acupuncture. The research in this

Burning surgery with a CO_2 laser treatment instrument

regard began in 1976 in China. Laser acupuncture machines being used include He-Ne, CO_2, YAG laser devices, and a N_2 molecular laser device. These machines have performed over a thousand clinical tests. The effect of laser acupuncture has been preliminarily justified. Several types of diseases have been treated with laser acupuncture with remarkable outcomes.

IV. Other applications

The invention of laser devices and the accompanying development of laser physics affect all of the optics very deeply. Scientists call the invention of the laser a "rebirth of optics".

Lasers have penetrated into every field of science and technology. The application of lasers in spectroscopy is one of the most successful applications. After applying lasers to spectroscopy, the spectral resolution has been increased one million times. The super-resolution spectroscopy which concentrates on lasers these days has been developed into a new branch of science. Scientists regard lasers as inducing a revolution in spectroscopy. This is not overestimated.

Scientists in China have been involved in the study of laser spectroscopy and have achieved remarkable progress. For instance,

the ruby laser has been used to stimulate benzene liquid and seven levels of Stokes lines have been observed. A very sharp first level anti-Stokes Raman spectral line was also observed, along with other new phenomena. Following Raman theory on excitation, the spectral lines of lower level must first appear, followed by partial spectra. Moreover, the intensity of the spectrum must decrease with increasing level. But "level jumping"* has been observed during experiments. The fifth level spectral line may appear even if the third level, the fourth level lines are missing, or sometimes the fifth level line is more intense than the third level, fourth level lines.

When the electro-optical switching multi-frequency YAG-Nd laser penetrates a quartz fiber, a 10 order of Stokes excited emission of 5460~6840 Å is observed. This could be a simple frequency conversion device.

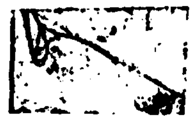
Research on multi-frequency of light is also impressive. Multi-frequency pulsed light is used to stimulate organic dye liquid in which degenerate four wave frequency mixture is observed.

Scientists in China also express interest in laser applications in chemistry, particularly in the research of laser separation of isotopes. The research was started in the early 1970's and substantial results have been obtained. In 1976, sulfur was successfully separated from SF_6 by a pulsed CO_2 laser* (following page). Later, the isotope B^{10} was separated from BCl_3**; the isotope deuterium was separated from formalin***. Currently, scientific workers in China are developing a new method to separate the isotope uranium with lasers.

*"Observation on the high-level excited Raman scattering", "Laser", 1978, 5, no. 5~6, 22.

In fiber optical communications, China has been in a practical development stage. Testing has been performed for telecommunication with fiber optical cable. A 5.7 km, 120-channel telephone experimental system has been implemented. The system was operated continuously for 2000 hours without losing its major functions. The optical fiber being used for optical communication has reduced average loss per kilometer to 5 db.

fiber-optical communication
machine (5.7 km)



optical cables and connection

UPGRADING

Laser technology has been developed over more than a decade. As our perception of lasers becomes more and more profound, many new problems arise whenever progress is made. Those problems need quick solutions and breakthroughs in order to push laser

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* "Separation of isotopes with TEACO_2 laser device", "Separation of sulfur isotopes with laser", "Laser Journal", 1978, 5, no. 5-6, 13.

** "Separation of boron isotopes with infrared multi-photon absorption", "Laser Journal", 1978, 5, 5-6, 14.

*** "Separation of condensed deuterium from formalin with multi-photons", "Suchuan University Journal (Science edition)", 1978, no. 4, 63.

technology ahead. On the other hand, we have to envisage the laser technology gap in comparison with other countries and try to catch up. Accordingly, we need to emphasize the "upgrading" of basic research.

Under the direction of "emphasis on basic research, emphasis on upgrading", research and development have been upgraded in many ways. The "Fourth National Conference on Laser Technology" is one of many meetings. The highlights of the meeting are summarized below: 1. Number of papers regarding theoretical analyses increased; 2. emphasized new type device research; 3. increased topics on filling gaps; 4. enhancement of research on quality upgrading of devices; 5. the quality of theories and experiments was raised. The tendency appearing in the meeting pleased us. It appealed to the Premier Chou's ideology: "Scientific research must be upgraded based upon extensive and profound practices". It also appealed to the demands for enhancement of basic research.

In the meeting information and achievements on laser basic research and partial applied research were exchanged, along with discussions on some key problems in laser research and direction of future efforts. A great deal of research accomplishments appeared in more than 250 reports and papers. Some of them were upgraded to a certain level. For example, the one-dimensional fusion model of laser-induced nuclear fusion transmutation was formulated with its own characteristics. Its calculated results are in good agreement with experiments. As for the interaction of intense light with atoms and molecules, the limitations of perturbation theory were pointed out and a new method of calculations for an intense light environment was proposed. New phenomena were observed in the basic experiments on laser excited fluorescence, laser plasma X spectrum, etc. Those phenomena bear further investigation. Extensive research work was performed on the harmonic oscillation cavity theory and the relation of laser nonlinear transport in a medium to the development of laser technology.

Some high quality papers were presented on communication data and drew a lot of attention. Those papers fully addressed some important points of view regarding communication volume. For laser materials, technical progress was made along with research on the basic physical properties of materials.

In summary, the conference marked a milestone which summarized the history of the development of laser technology in China and also affects the future evolution of the technology. The conference was the most important one in the history of laser development****.

(to be continued)

**** "A splendid conference on laser scientific research", "Laser Journal", 1978, 5, no. 5-6, 1-2.